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WDM Optical Communication System

The present invention relates to a WDM optical communication system with Raman amplification.

Optical communication systems are a fast-growing constituent of communication networks. The term "optical communication system" as used in the following relates to any system or device which makes use of optical signals to transport information across an optical waveguiding medium. Optical communication systems comprise inter alia telecommunication systems, local area networks (LAN), cable television systems etc.

Wavelength division multiplexing (WDM) is a technique which allows to increase the capacity of fibre optic networks. In a WDM system, a plurality of optical channels are carried over a single waveguide, each channel being assigned a particular wavelength. The use of WDM systems for signal transmission is described in US-5,959,750, the disclosure of which is incorporated herein by reference.

For the transmission capacity of optical fibres in optical communication systems is expected to advance in the future, the evolution of optical amplification is one of the core technologies involved in this process. A key to this evolution is the availability of extremely-broad-band optical amplifiers, offering amplification over nearly all the transmission window allowed by silica. These requirements can be met inter alia by Raman amplification.

Optical fibre Raman amplifiers (FRA) are well known and are known to be designed to operate at a desired wavelength between 1.25 μm and 1.7 μm. FRA utilize silica-based fibres and display a high transparency when unpumped. The working principle of FRA is based on stimulated Raman scattering as for example explained in the Ph.D. thesis of P. Riedel with the title "Untersuchungen zum künftigen Einsatz solitonengestützter faseroptischer Nachrichtenübertragung bei 1,3μm Wellenlänge", Hamburg 1998, the disclosure of which is

incorporated herein by reference. FRA can serve for example as a replacement for conventional repeaters or semiconductor-amplifiers, or for rare-earth-doped fibre amplifiers or in combination with them.

Y. Emori and S. Namiki disclose in OFC (Optical Fibre Communications Conference) 99, PD19-1 to PD19-3 Raman amplifiers which are pumped and gain equalized by 12-wavelength-channel WDM high power laser diodes. Every laser has to be multiplexed by a 11-MZI-planar lightwave circuit (PLC) and individually power-supplied by means of a controlling unit.

When Raman amplification in optical communication systems is used as mentioned above , i.e. in combination with several WDM wavelength pump channels, interference between adjacent pump channels will occurr, i.e. they "crosstalk". This is due to stimulated Raman scattering and four-wave-mixing. Therefore, significant pumping efficiency will be lost in addition to pump instabilities caused by polarisation of the interfering channels.

Several solutions for these problems have been proposed:

The use of a Raman fibre laser as pumping means provides a high pump efficiency output which is located in only one channel. The use of two or more Raman fibre lasers is possible but is more costly and power-consuming. Raman lasers are not polarized.

Alternatively, the use of two semiconductor pump lasers for each required pump wavelength combined with a PBC (polarisation beam combiner) has been proposed, which allows to obtain an unpolarized output. However, this leads to a loss of power at the pump output in the range of 0.5 dB to 1 dB and requires an additional step in the fabrication of the Raman pumps. Moreover, this solution affords twice the number of pump units for a given number of pump channels. This doubles the overall cost and the costs of the PBC are high.

Another alternative is to use a single semiconductor pump laser for each required pump wavelength and to depolarize it by use of a polarisation maintaining fibre of a length L from about 10 to 100 m where its principal axis is rotated by 45° with respect to the principal axis

of the polarisation maintaining fibre pigtail of the laser. This principle was used in Bigo et al. ECOC '00 (postdeadline paper no. 2), Munich 2000. In the experiment described in this paper each of the four pump lasers used for distributed Raman amplification was depolarized by this technique. However, the solution is not fully satisfactory, as firstly, a perfect depolarisation could not be obtained and secondly, the introduction of the polarisation maintaining fibre induced losses in the pump path of about 0,5 dB.

In addition all prior art systems described in the foregoing do not reduce the pump cross-talk.

The underlying problem of the present invention is therefore to avoid polarization effects in multichannel WDM pumps used in Fibre Raman Amplifiers (FRA) for localized as well as distributed Raman amplification while maintaining a high pumping efficiency and to reduce cross-talk between pump wavelengths.

This problem is solved by a WDM optical communication system with Raman amplification with the features of claim 1.

Accordingly, a WDM optical communication system, comprises input means and output means for an optical signal, an optical fibre path connecting signal-transmissively said input and output means, wherein the optic signal is amplified by means of Raman amplification and said optical fibre path comprises at least one Raman amplifier, further comprises WDM means for coupling at least two polarized pump radiation wavelengths with wavelengths less than the signal radiation wavelength into said Raman amplifier, whereby one pump radiation wavelength has a selected different polarization with respect to the polarization of the other pump radiation wavelengths.

This pump arrangement according to the invention with a suitable selection of the polarization provides a larger Raman gain with up to several dB more in signal-to-noise ratio (SNR) by reducing considerably the cross-talk between the pumps. It does also reduce the instabilities in the gain.

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Preferably, the Raman amplification is a distributed Raman amplification with less noise compared to lumped Raman amplification. In another embodiment, the Raman amplification is localized Raman amplification.

In an advantageous embodiment, at least one pump radiation wavelength has a polarization which is orthogonal with respect to the polarization of at least one other pump radiation wavelength.

It is particularly preferred that only the polarization of the lower part of the pump wavelengths multiplex is orthogonal with respect to the upper part. For example, the pump wavelengths are between 1420 and 1500 nm and the signal in the C and L band is between 1525 and 1610 nm. Particularly, using three pumps (the first three: lower part) out of exemplarily four pumps and using an orthogonal polarization for the fourth spaced apart one (upper part), is highly efficient, because most pump cross-talk through Raman scattering takes place between the extreme pump channels.

It is understood that the aforementioned advantages and the features of the invention explained in the following, are not only used in the specifically described combination, but can also be used by a person skilled in the art in other combinations or alone, without exceeding the scope of the invention.

The invention is schematically explained in figures 1 and 2 and is described in detail, where reference is made to the drawings.

Figure 1 schematically shows an embodiment of the invention when using 4 pumps.

Figure 2 schematically shows a diagram which indicates the Raman interactions between two orthogonal polarized and between two copolarized wavelengths.

Figure 1 shows the working principle of the invention. In this specific embodiment, 4 different pump wavelengths are used. The three pump wavelengths at 1427, 1439 and 1450 nm are strongly interacting with the fourth pump wavelength when they are depolarized but are not

interacting when they are polarized and the pump wavelength 4 is orthogonal with respect to the other three pump wavelengths.

Figure 2 shows a diagram which indicates the Raman interactions between two orthogonal polarized and between two copolarized wavelengths. The diagram shows the Raman efficiency C_R

($W^{-1}km^{-1}$) related to the difference $\Delta\nu$ of the frequency of the pump and of the respective channel. The first curve denoted with the sign $\perp$ shows the behaviour for two orthogonally polarized wavelengths. Curve 2 is denoted with the sign $\|$ showing the behaviour for two copolarized wavelengths. Curve 3 referenced to as $(\| + \perp)/2$ shows the behaviour for two unpolarized wavelengths.

Figure 2 further shows two different areas, denoted with the numbers 1 and 2. Area 1 shows the Raman interaction behaviour of curves 1 to 3 in the case that the wavelengths of the pump (for example at 1427 nm) and of the signal, for example at 1439 nm, are spaced apart with less than 5 THz. As can be seen from area 1, the behaviour in all three cases shows about the same effect.

As can be seen in area 2 for differences in wavelength spacing with more than 5 THz, the energy transfer between the two wavelengths is at a maximum when they are copolarized and is halved when they are depolarized. The effect of the present invention can be seen in curve 1 in area 2, where this energy transfer is minimal for orthogonally-polarized wavelengths. Examples of wavelengths corresponding to this case are 1427 and 1485 nm.